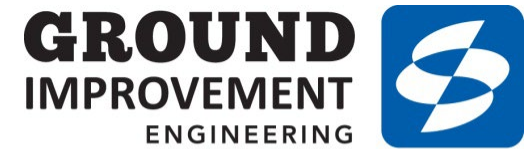


# GEOPIER®



## Ground Improvement Solutions

**Delivering the Advantages  
on your Challenging Site Conditions**

Leading. By Design.

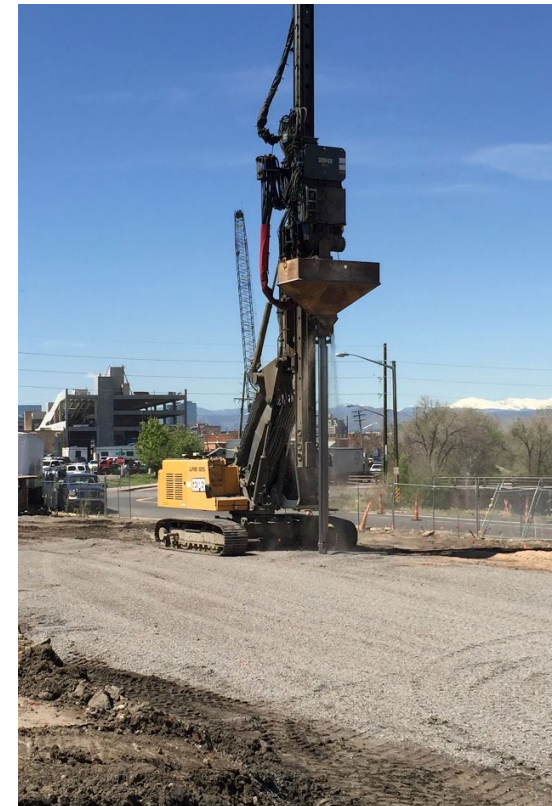


**NSPE-OK**  
OKLAHOMA SOCIETY  
OF PROFESSIONAL  
ENGINEERS

# Outline

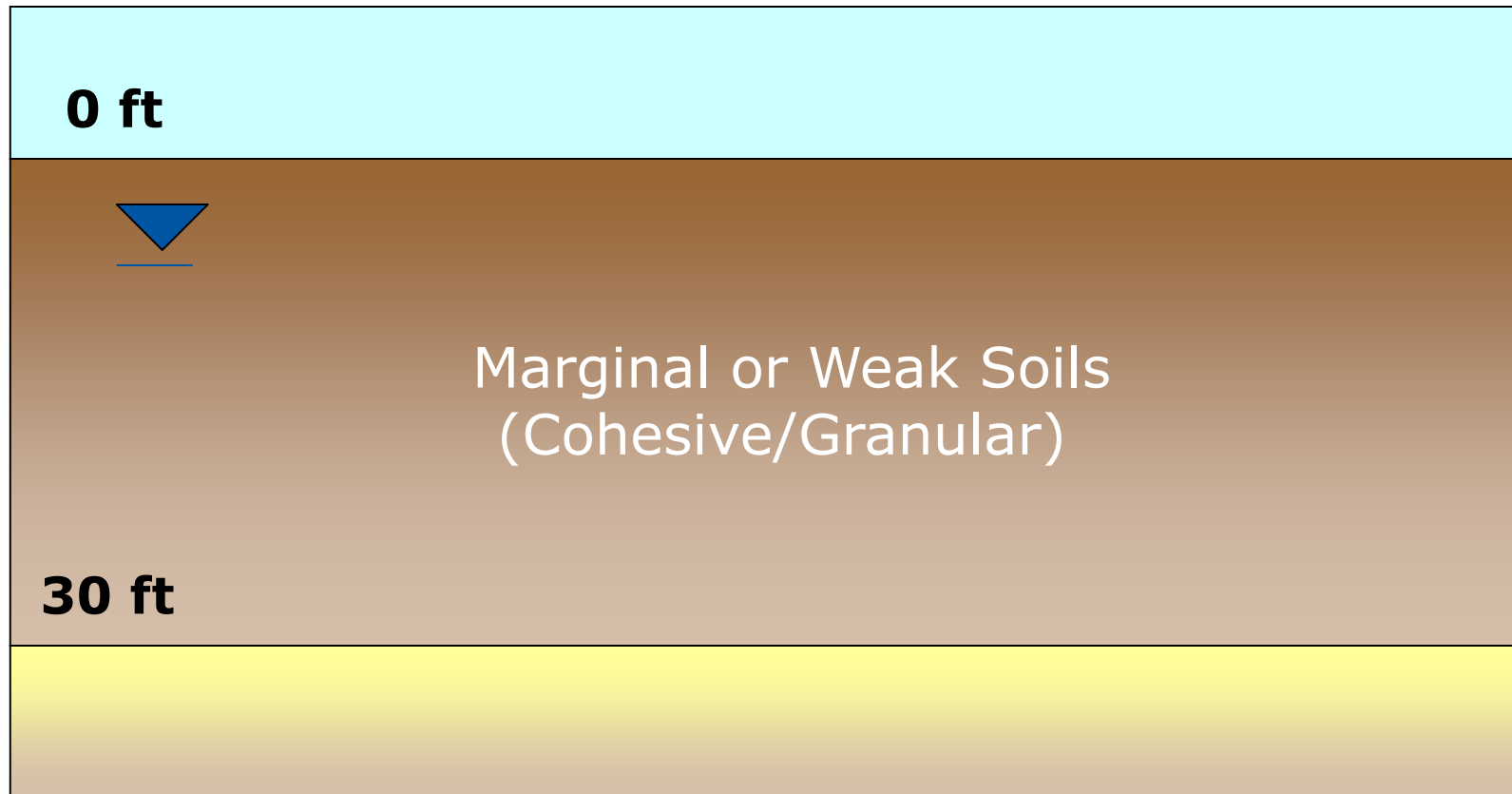


- What – Why – How ??
- Design Basics – Foundations
- Design Basics – Floor Slabs
- When to Consider Ground Improvement
- Project Examples



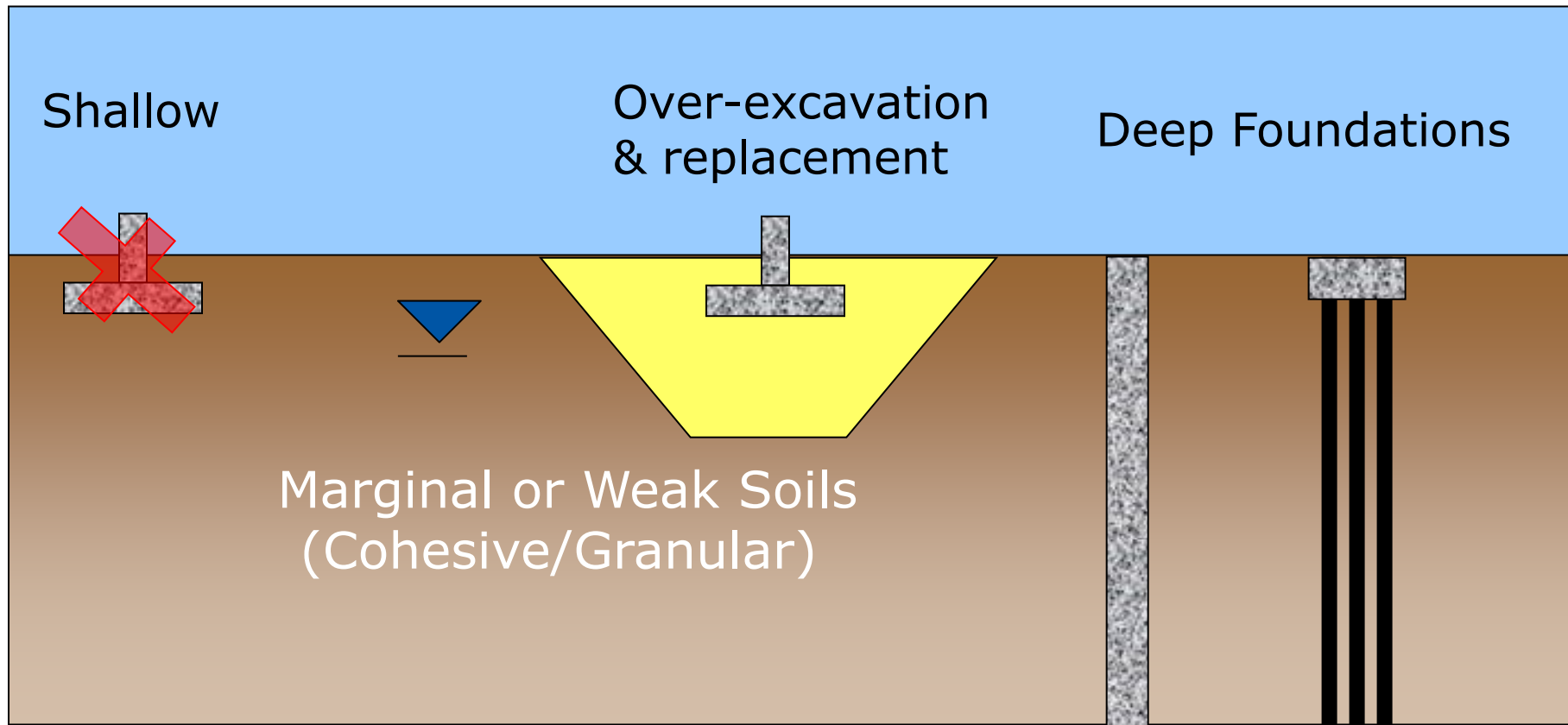


Suppose a **6-story parking structure is** planned for this site, what traditional foundation support system would you consider given the following conditions?



# History of Foundations (why)

Past choices:

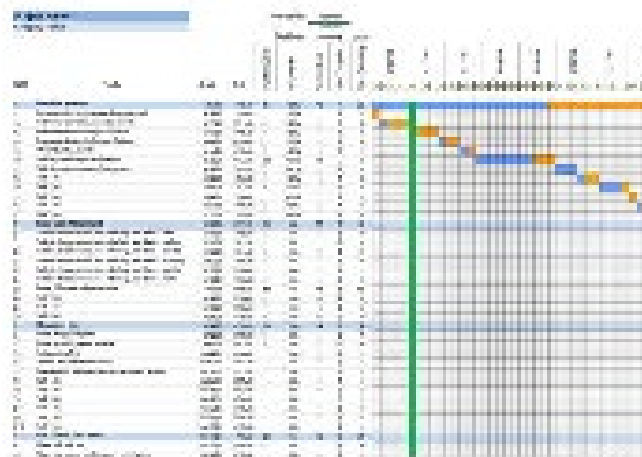


What are the downsides to traditional methods?



Low Allowable  
Bearing Capacity  
(large footings)

Cost



Extended  
Construction  
Schedules

Other downsides:



Deep excavations

Dewatering

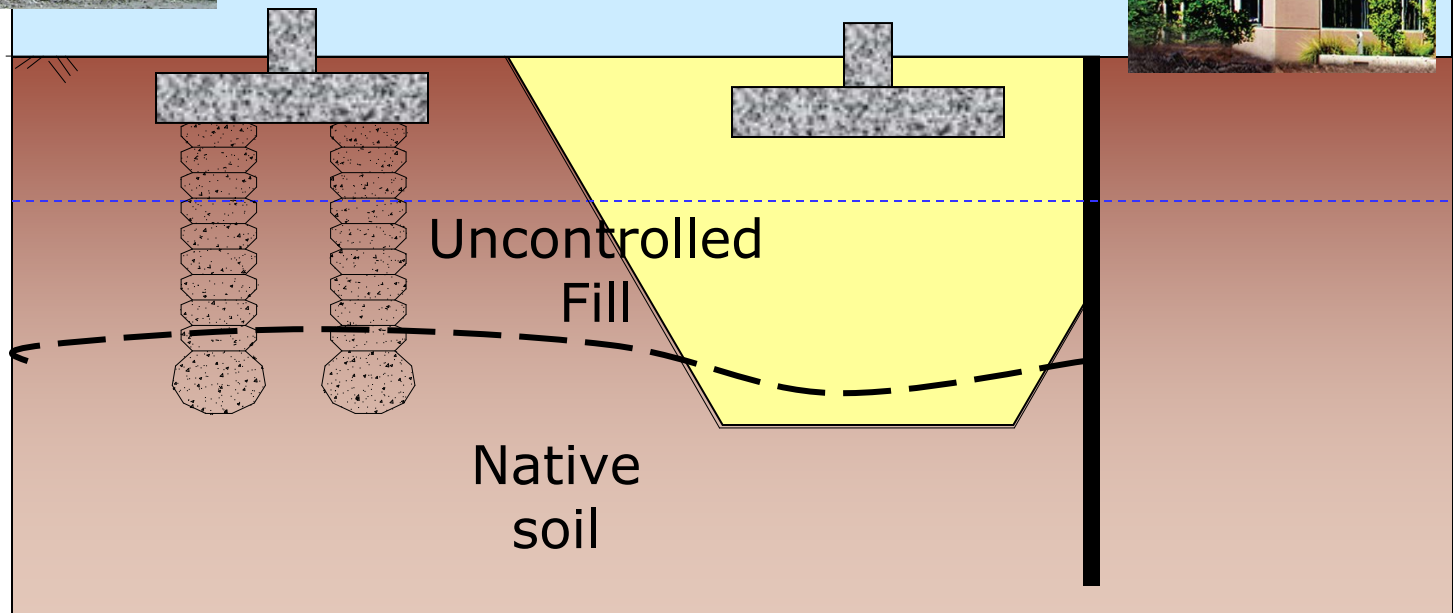




Other downsides:

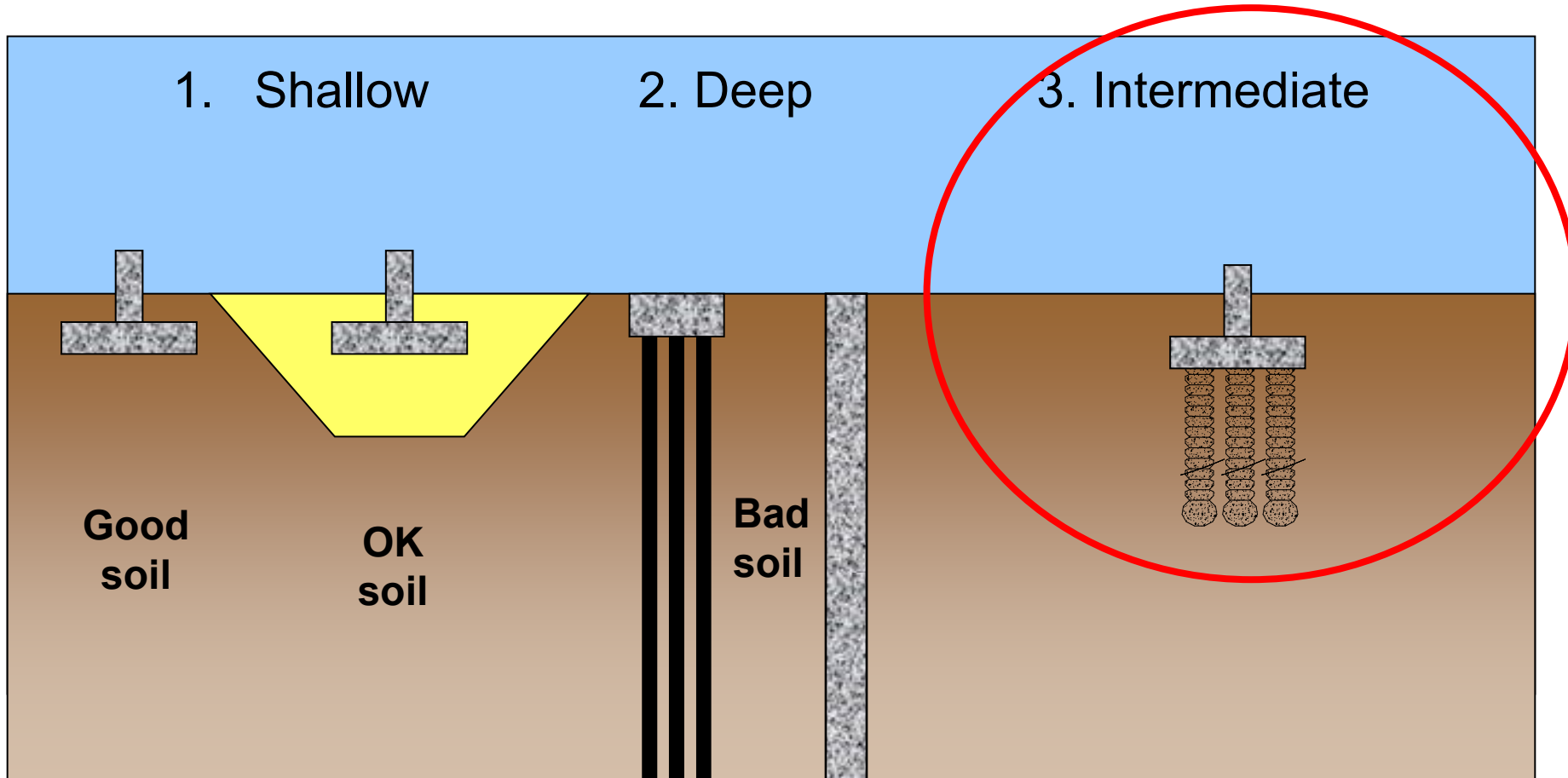


Shoring





In late 1980's a third choice emerged:  
INTERMEDIATE Foundation® systems (which are actually  
methods for in-situ soil reinforcement)





Intermediate Foundation Systems designed by Ground Improvement Engineers are referred to as “Rammed Aggregate Pier<sup>®</sup>” reinforcement systems.

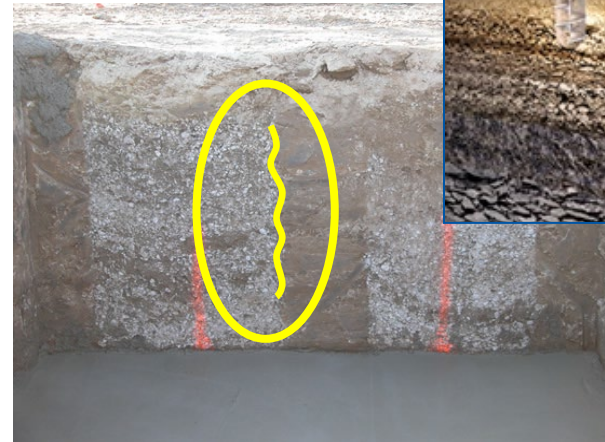
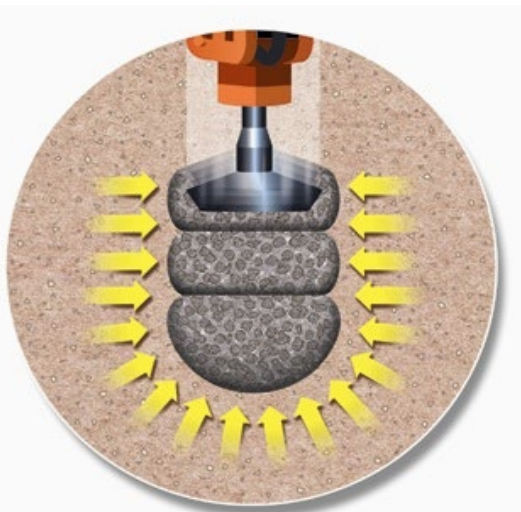


With time, the Rammed Aggregate Pier (RAP) foundation systems have gained in popularity (cost and schedule).

# How Intermediate Foundations Work



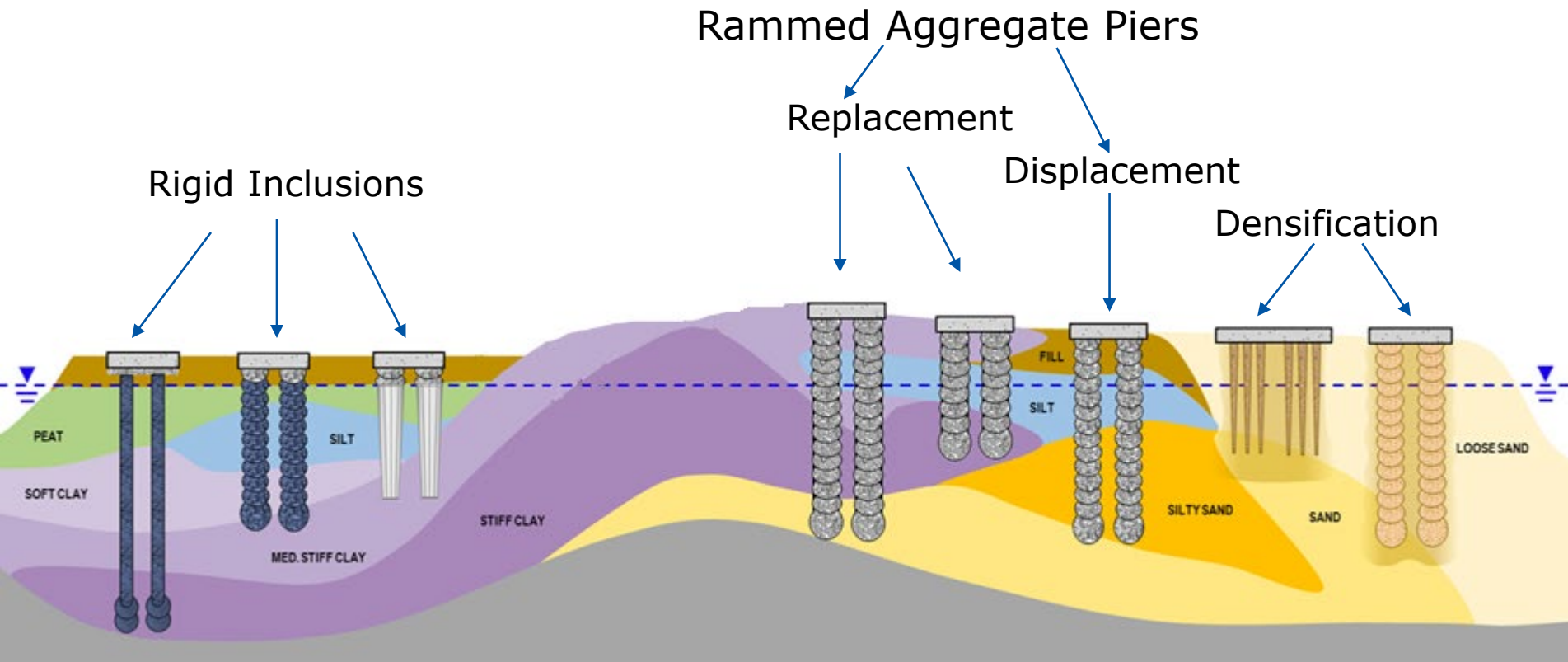
- Improve the Ground In Place
- Composite Subgrade with Highly Densified Aggregate Element and Improved Matrix Soil
- Increased Shear Strength
  - Greater Bearing Capacity
- Increased Subgrade Stiffness
  - Settlement Control
  - Static & Dynamic Support



Undulated Sidewalls  
(Rammed Into Matrix Soil)



## GEOPIER<sup>®</sup> Technologies





## Multiple Ways To Deliver The RAP Solution

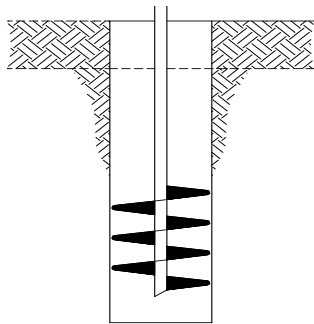


Replacement  
(Drill and Fill)

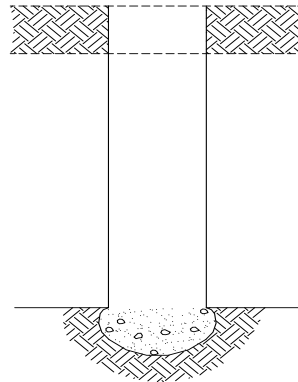


Displacement  
(Impact<sup>®</sup>)

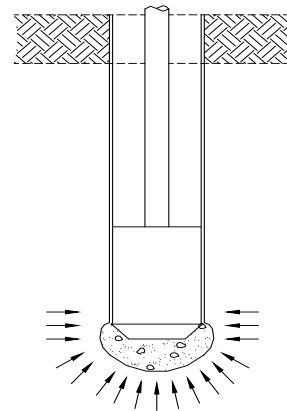
# Geopier Construction



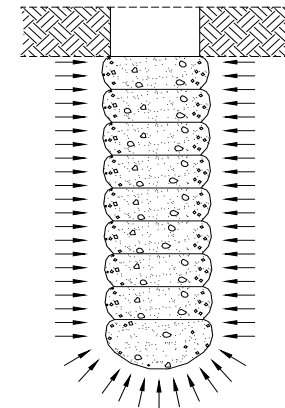
Excavate  
cavity



Open-graded  
stone



Tamp bottom  
bulb



Aggregate tamped  
in 2'-4' lifts

# Geopier Construction

**GROUND  
IMPROVEMENT  
ENGINEERING**



Displacement Method (Impact<sup>®</sup>)

# Displacement Considerations and Advantages



- Soft / caving silts and clays
- Loose sands
- High groundwater sites
- No spoils (**contaminated sites**)
- Foundation and slab support, liquefaction mitigation

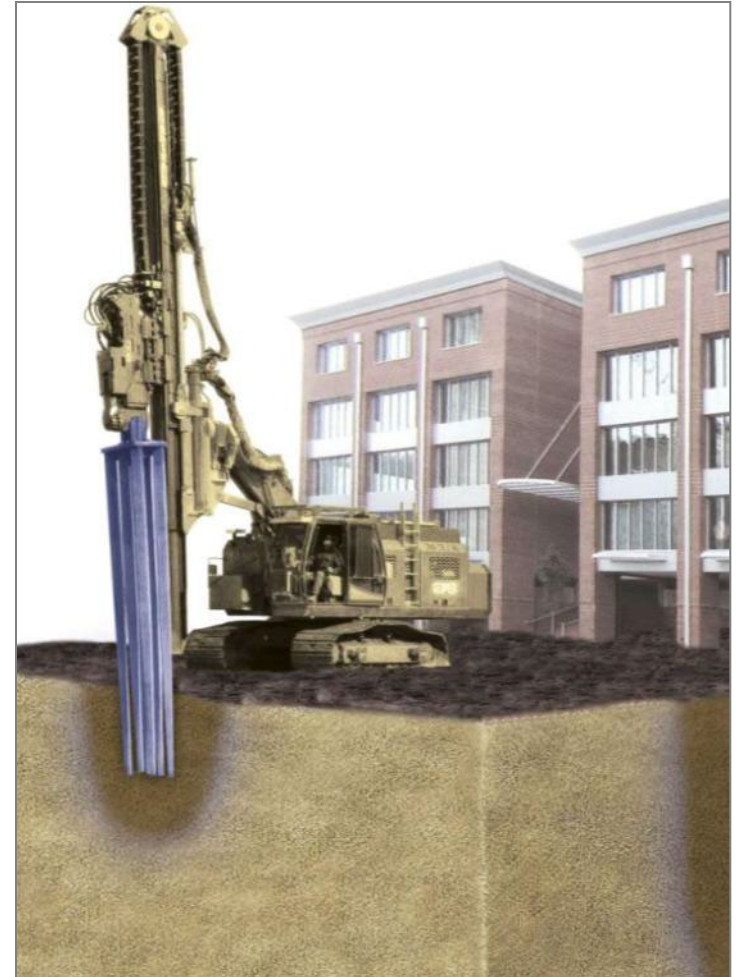


# Geopier Densipact System

**GROUND  
IMPROVEMENT  
ENGINEERING**



- Must be a clean sand site
- Multiple, tapered tines connected to base plate
- Driven up to 20 ft
- Vertical ramming energy & downward crowd force
- Significantly densifies existing granular soil or fill
- Installed in grids beneath large areas (slabs) & concentrated beneath footings



**DENSIPACT®**

## Multiple Tools for Rammed Compaction<sup>®</sup> Improvement



2m Tool



3m Tool



6m Tool

## Rammed Compaction<sup>®</sup> Construction Process



Drive tooling (1<sup>st</sup> pass)



Remove & Fill with  
sand

## Construction Process (continued)



Drive tooling (2<sup>nd</sup> pass)



Remove & Fill  
with sand

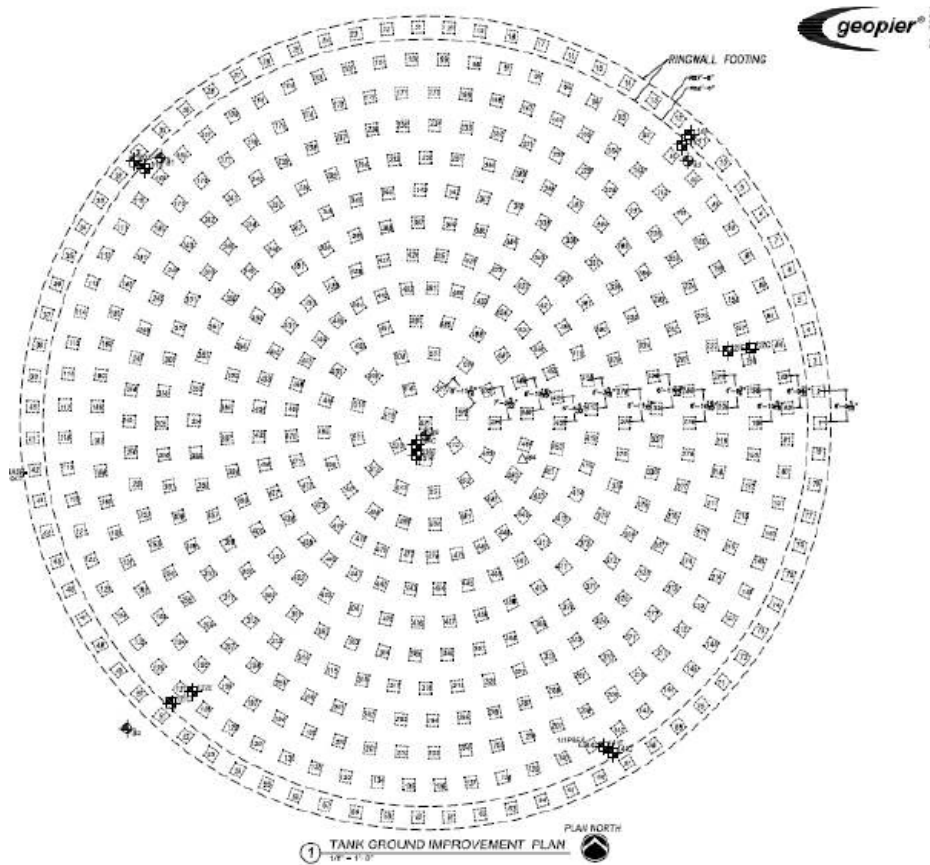


Followed by surface  
compaction

Drive tooling (3<sup>rd</sup> pass) & remove



## Terra Industries Tank– Woodward, OK

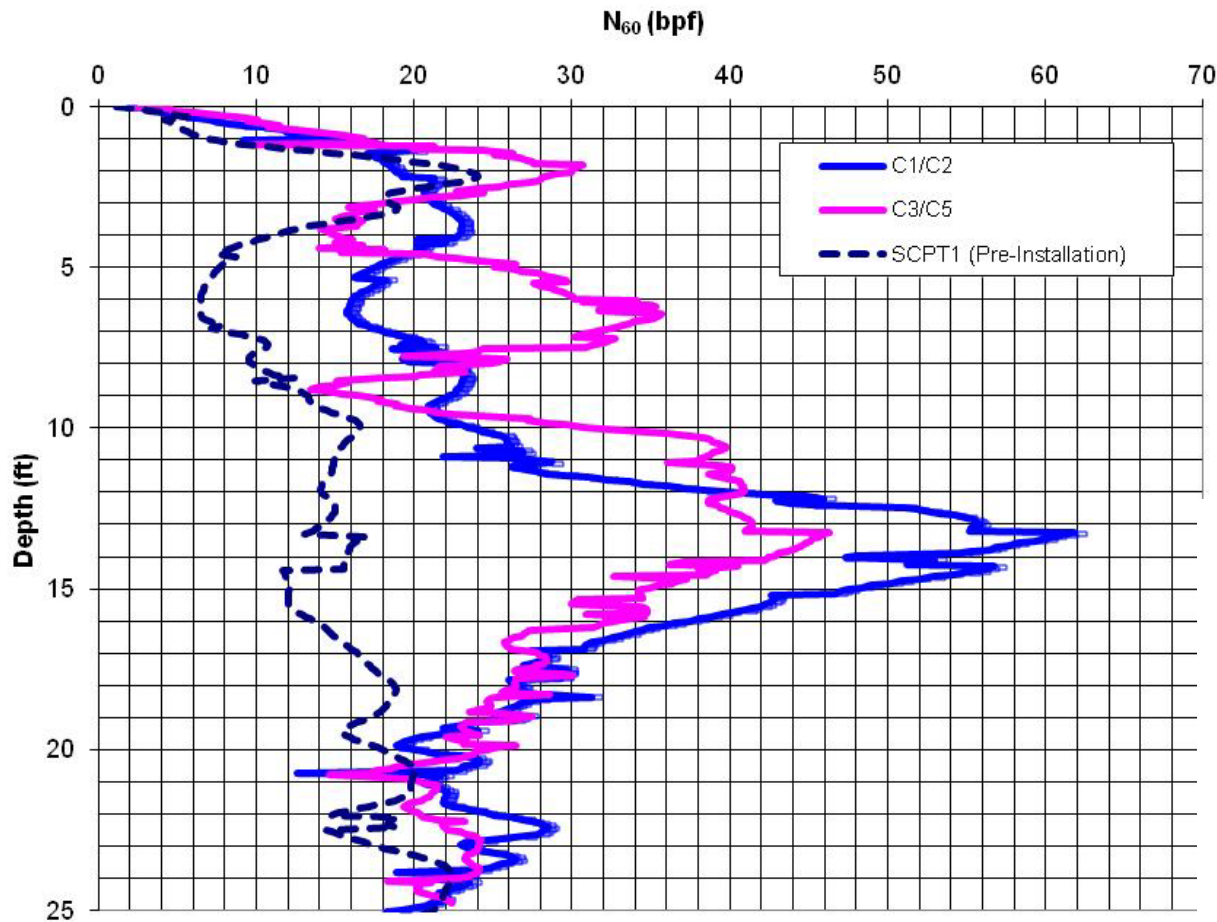


- Support 105-ft dia. Tank
- Pressure = 5,000 psf
- Loose sand (SP, SP-SM)
- 2m tool driven at 7 ft o-c

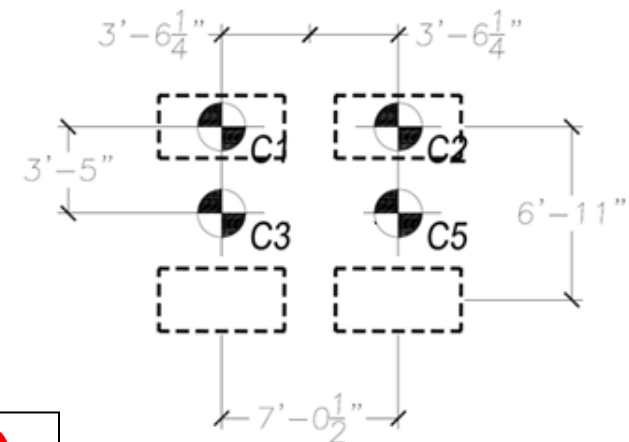




## Densipact Verification Program



**Penetration Increase:  $\Delta N = 20$  to  $30$  bpf)**





# Rigid Inclusions GeoConcrete® Columns

## State of Practice - Concrete Pumps

Small Volume Trailer Pumps



Medium Volume Track Pumps



High Volume Boom Pumps





# GeoConcrete® Columns QC

Initial

Drive

Bulb

Withdraw



$P_{air} = 0$



$P_{air} = \uparrow$



$P_{air} = \uparrow \uparrow \uparrow$



$P_{air} = \downarrow \downarrow$



$P_{air} = \uparrow$



$P_{air} = \downarrow \downarrow$



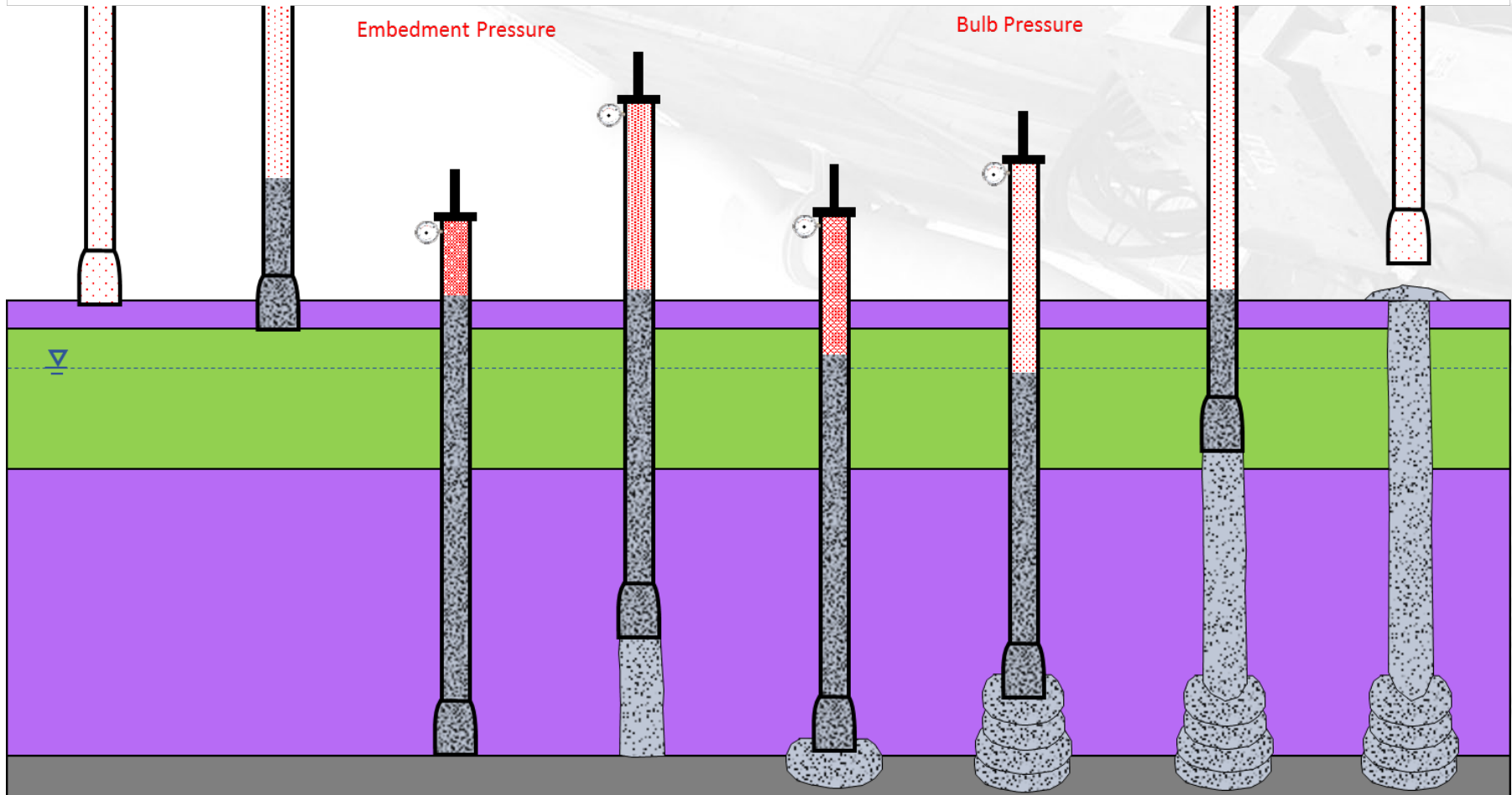
$P_{air} = \downarrow \downarrow$



$P_{air} = 0$

Embedment Pressure

Bulb Pressure





Some things are obvious...



...while others are not



## FOUNDATION SUPPORT APPROACH:

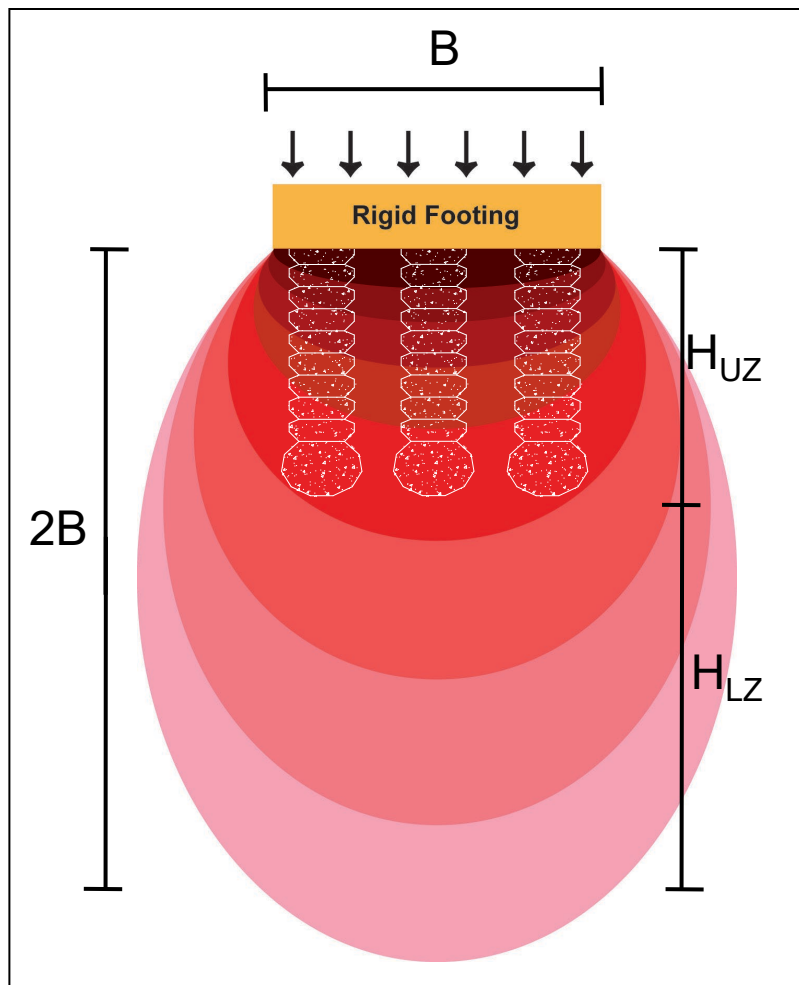
Construction of stiff composite reinforced zone in area of highest footing-induced stress



Strengthened Geopier-Reinforced Subgrade

How do Geopier systems work?

Replace weak soil with stronger /stiffer material



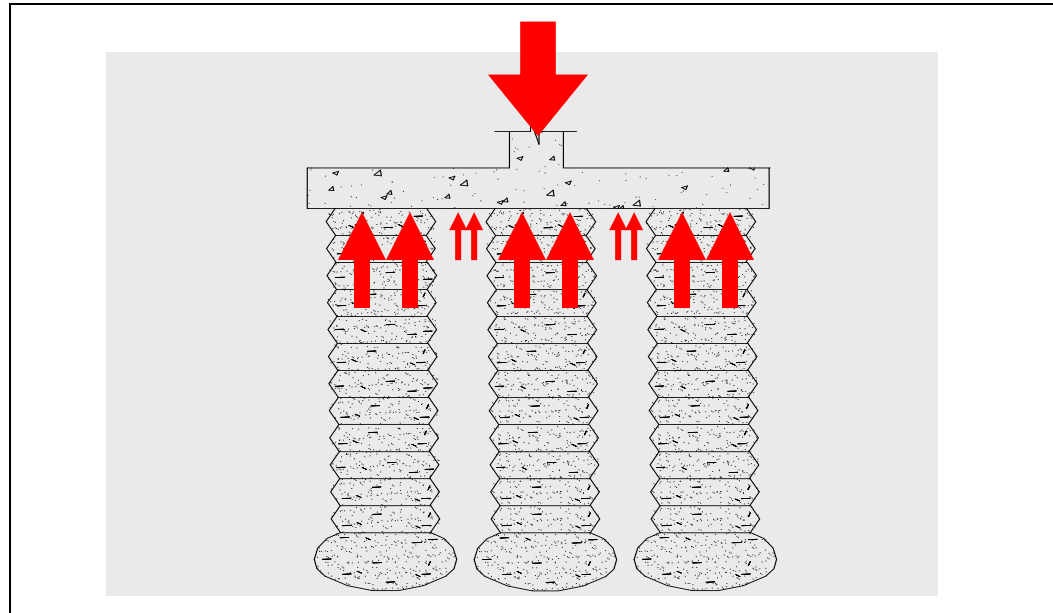
***Upper  
zone***

***Lower  
zone***

Now we have a stronger "*upper zone*" and an unimproved "*lower zone*"

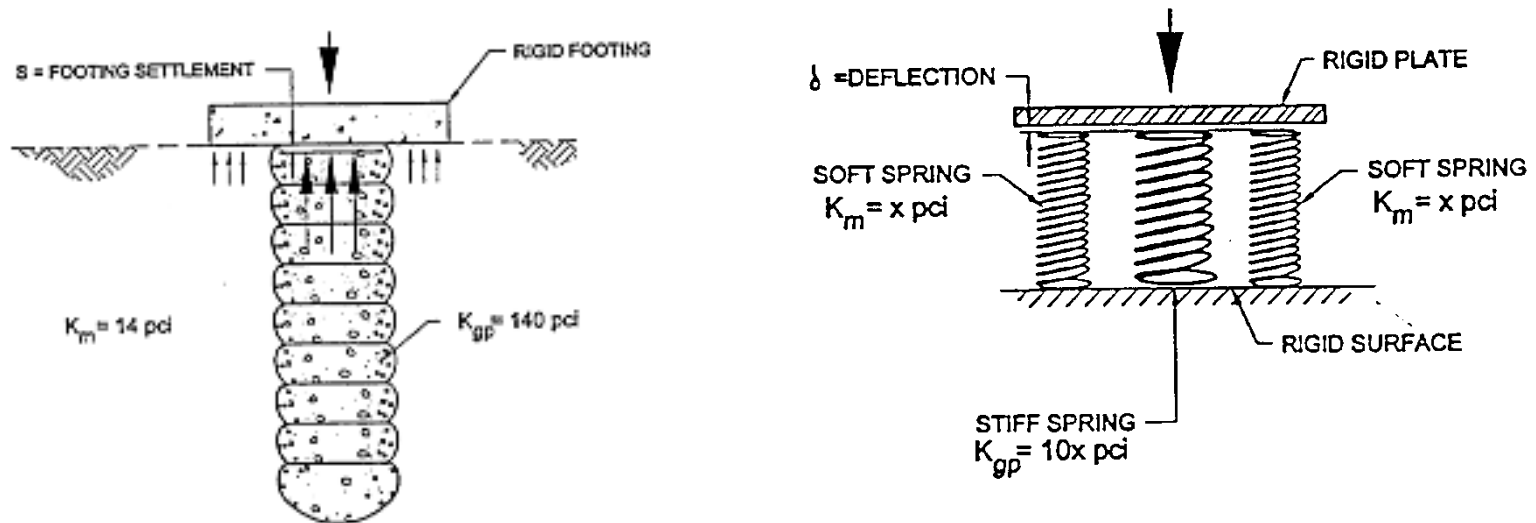
## How do Geopier systems work?

Focus on the “upper zone”



Push down on footing, the stiff element (pier) takes more of the load

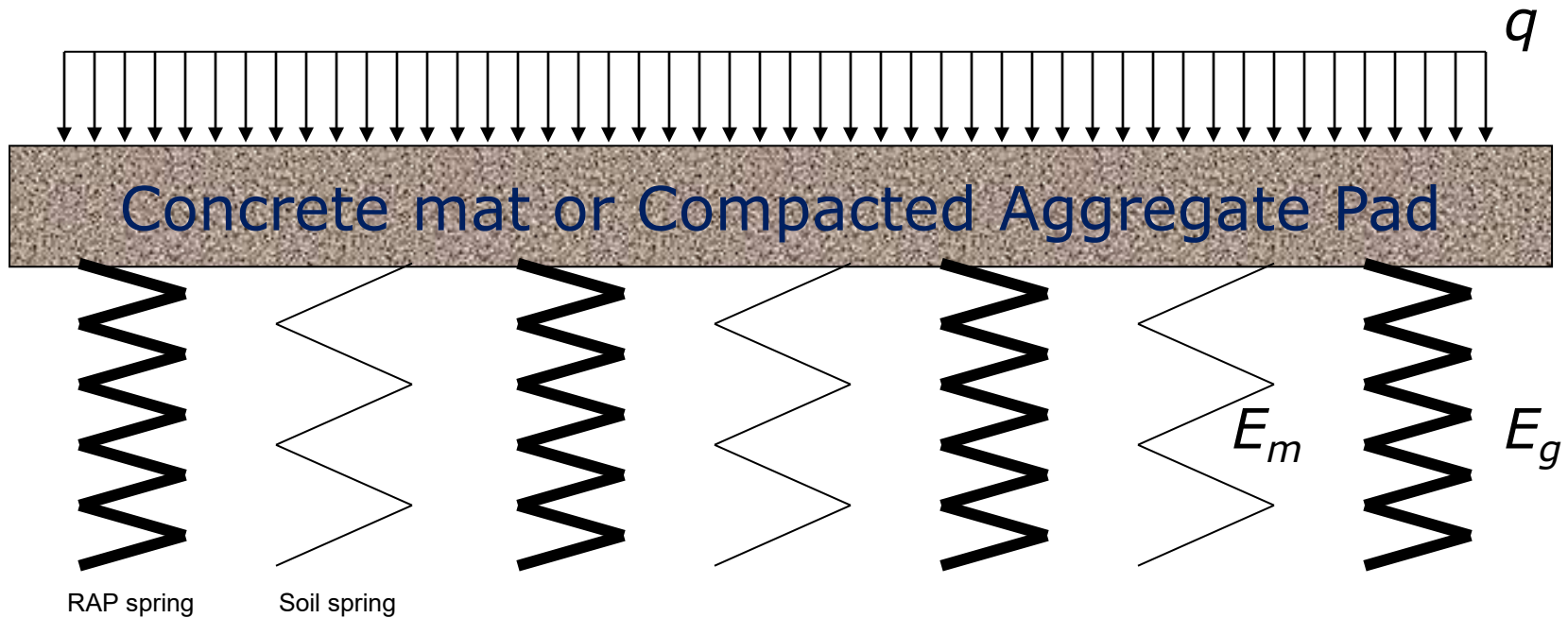
## Settlement Within RAP Zone (Upper Zone)



### Design based on spring analogy:

- Stiff spring (RAP element) takes more load.
- Stresses redistribute in footing to concentrate on top of RAP elements, reducing stresses on matrix (native) soils.

## Upper Zone Design Approach - Composite



## Composite Behavior

$$s = \frac{q \cdot I \cdot H_{uz}}{E_{comp}}$$

## Upper Zone Design Approach - Composite

$$E_{\text{comp}} = (1-R_a) E_m + R_a E_g$$

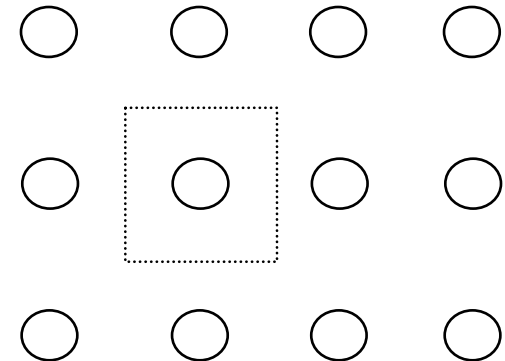
$R_a$  = Geopier area coverage ratio

$E_m$  = Matrix soil elastic modulus

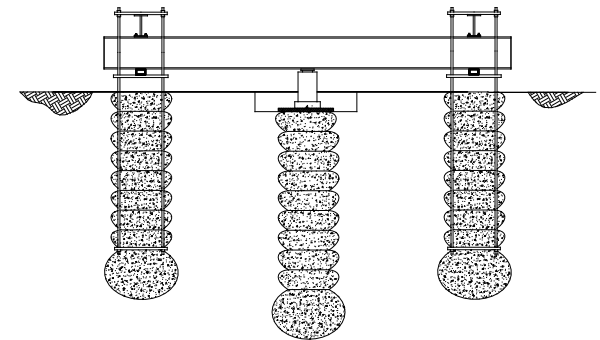
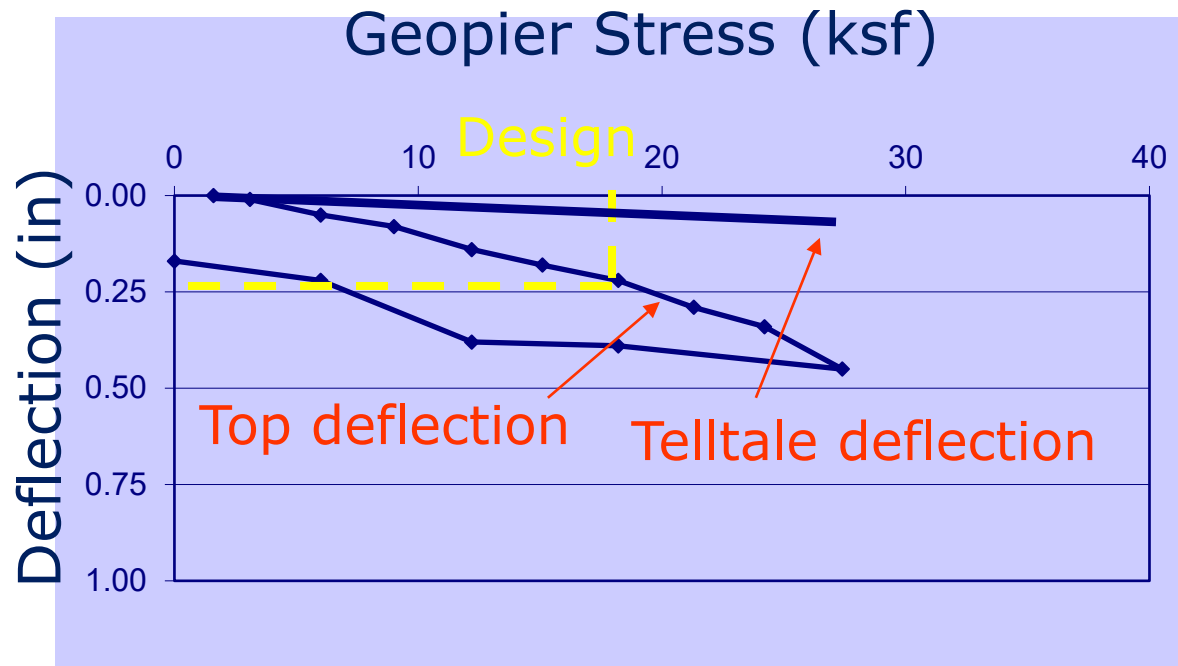
*(Based on correlations / testing)*

$E_g$  = Geopier elastic modulus

*(Based on modulus test results)*



The strength and stiffness of the pier determined using a Modulus Test which gives you a spring constant



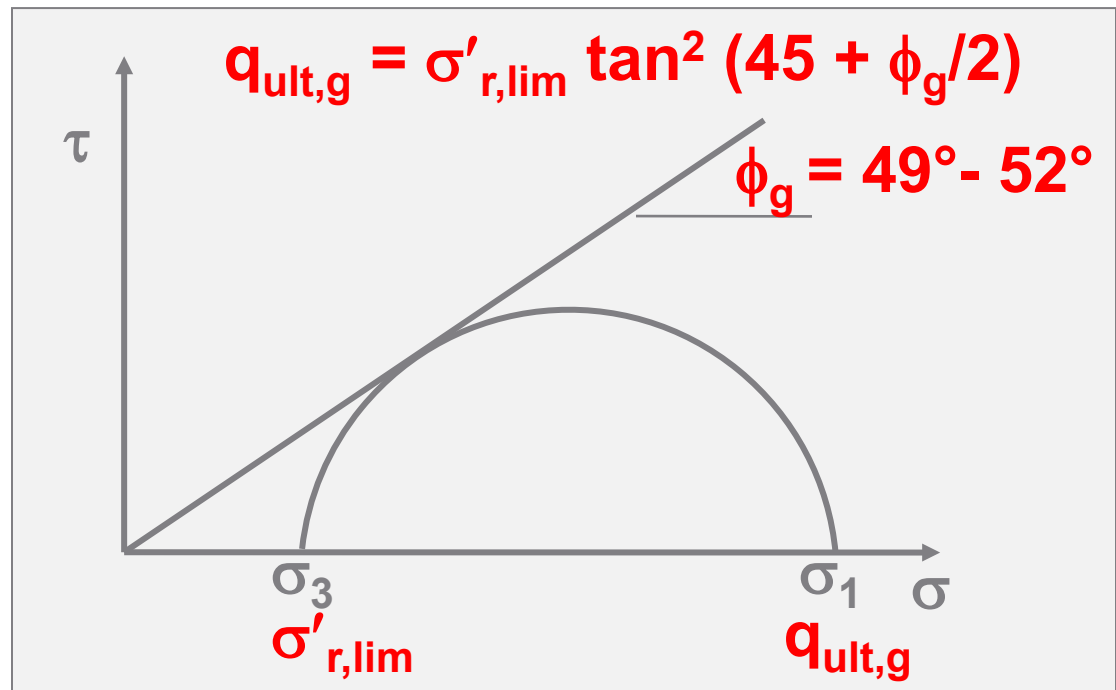
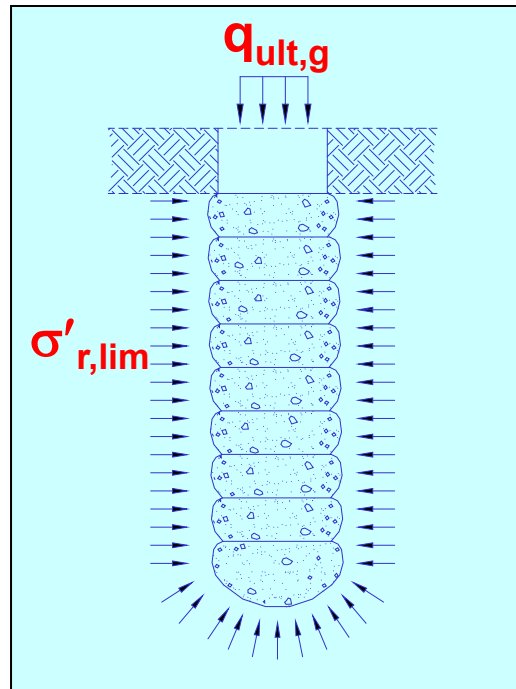
Deflection = 0.25-inch

- $k_g = \text{stress} / \text{deflection} = 500 \text{ pci}$

## How do Geopier systems work?

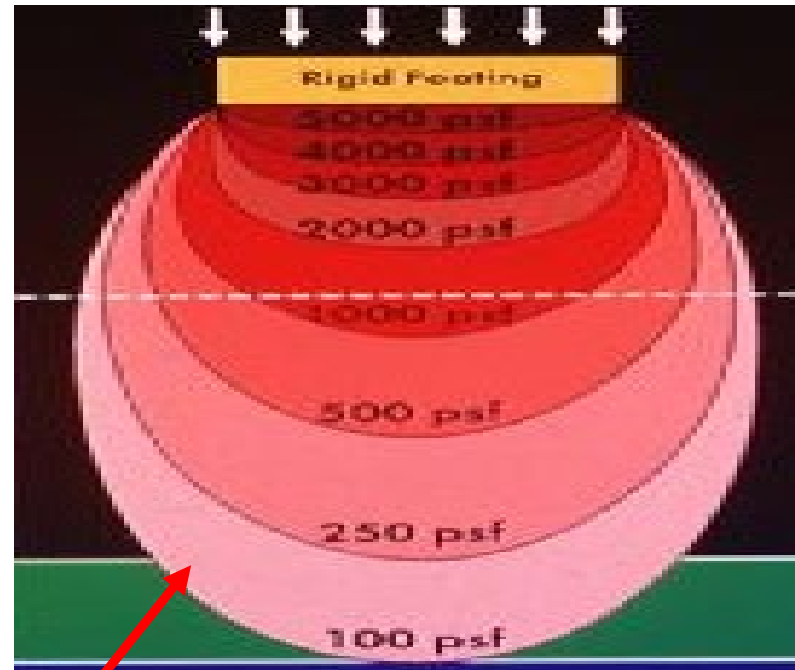
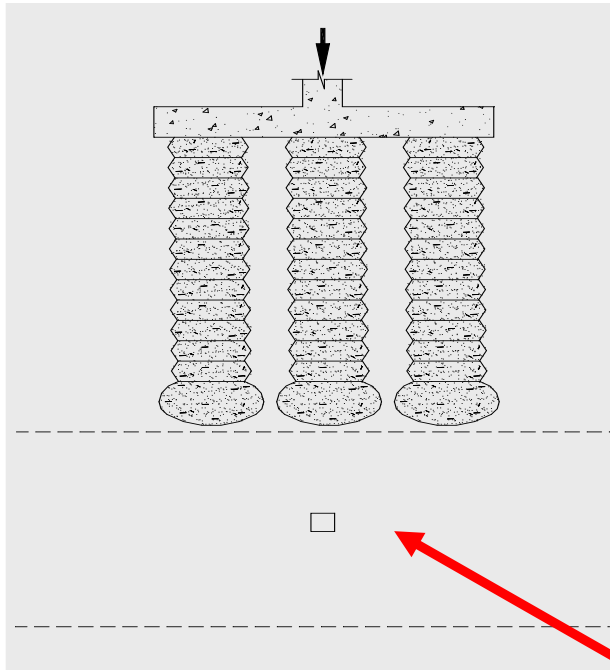
The strength of the pier depends on only two factors:

- The friction angle of the RAMMED aggregate, and
- The EFFECTIVE horizontal stress in the soil





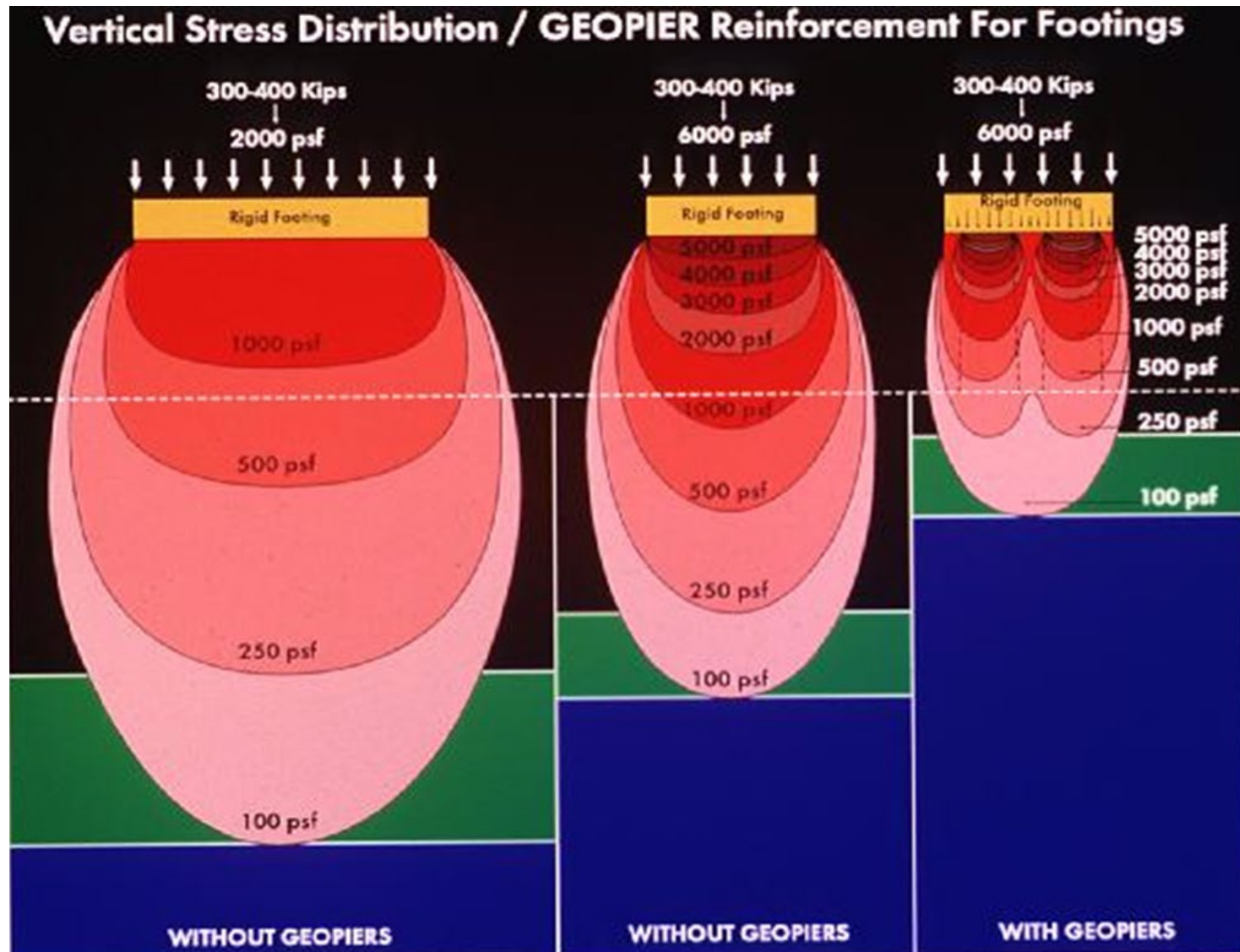
## Settlement below Geopier elements (Lower Zone)



Use stress influence factors to estimate footing-induced pressure at center of lower zone

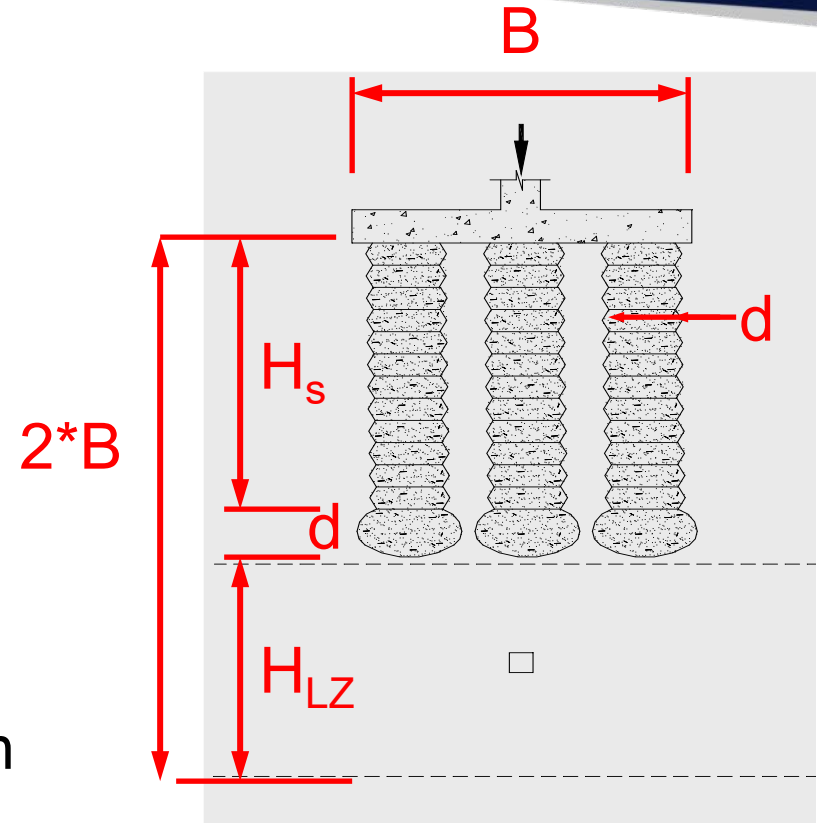


Much shallower stress distribution into the soil with Geopier



## Design Comments

1. Total settlement = upper zone + lower zone settlement
2. Increase shaft length to decrease settlement
3. Modulus test used to confirm
4. Database of modulus test results available
5. Lower zone compressibility - important parameter



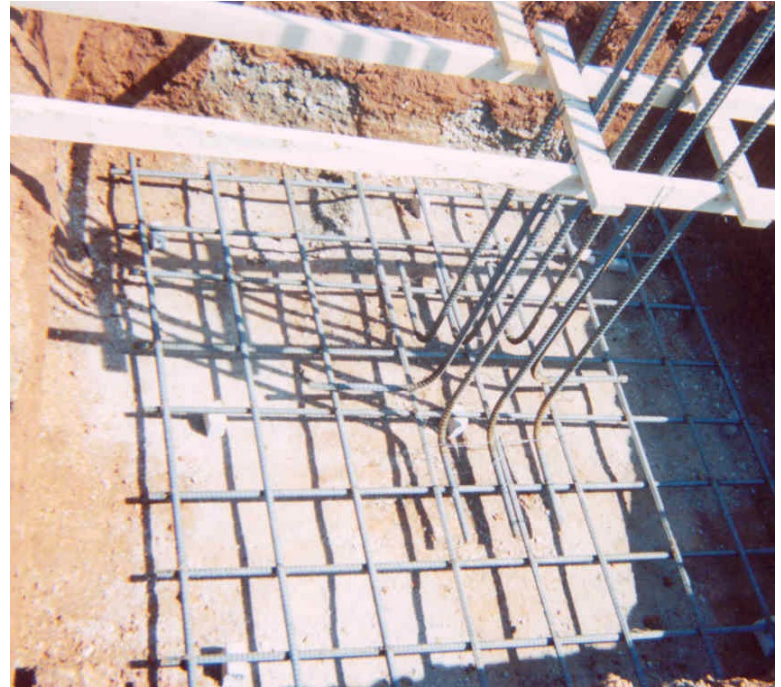


## Footings:

The GI engineer should demonstrate that stiffness difference between the pier and surrounding soils small enough for normal footing design

GI Engineer must design granular pad/load transfer platform for Rigid Inclusions

Bearing pressures of 3,500 to 14,000 psf may be used depending on GI technique and soil conditions



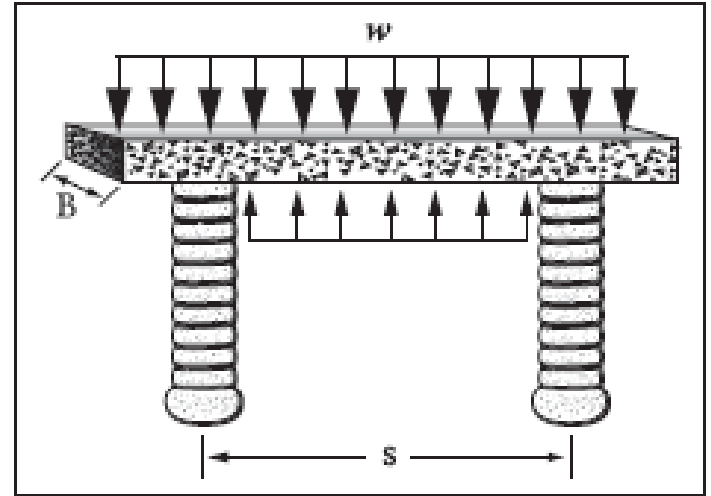


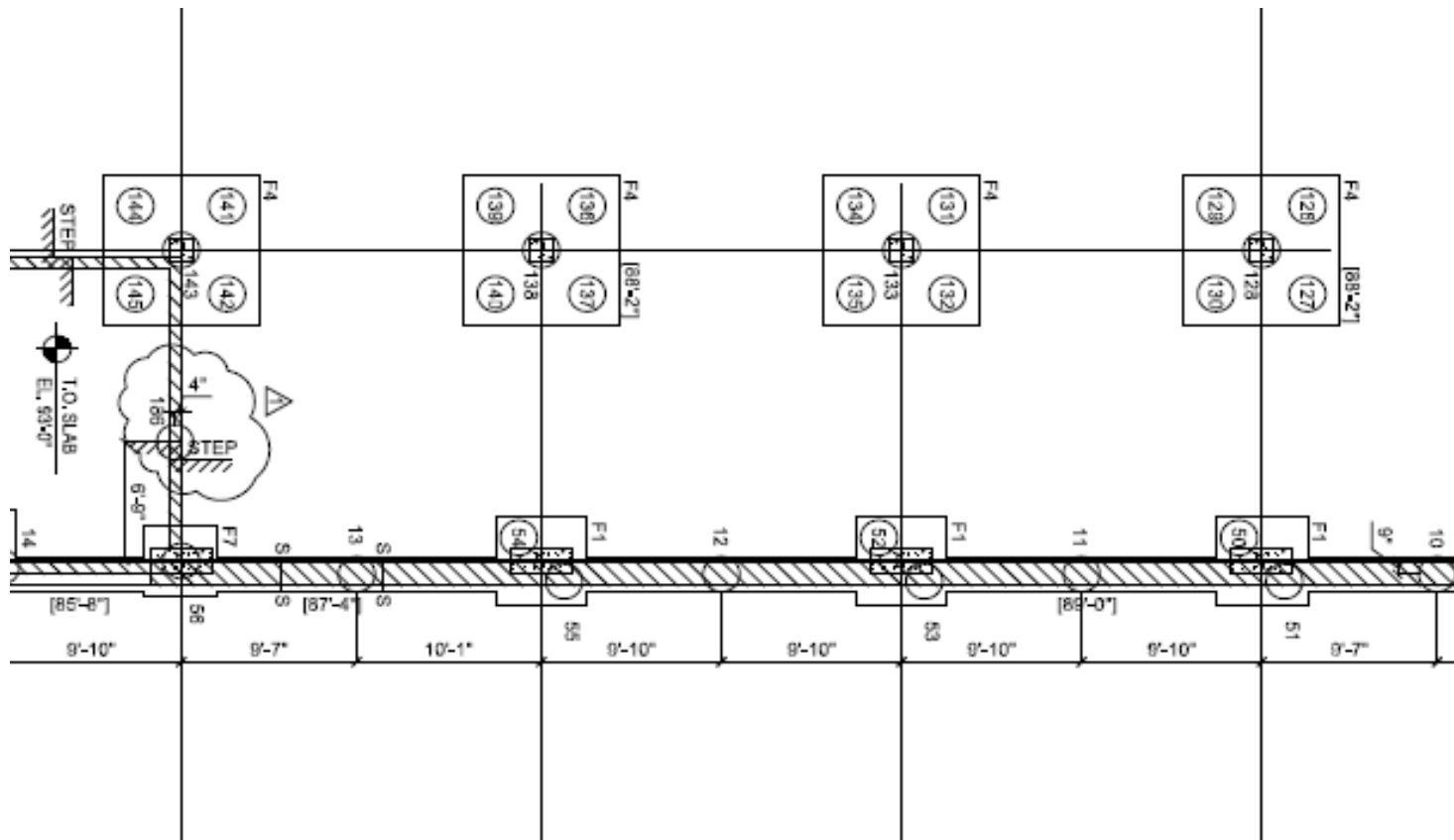
## Footings:

The GI engineer should provide settlement calculations for each strip and spread footing type

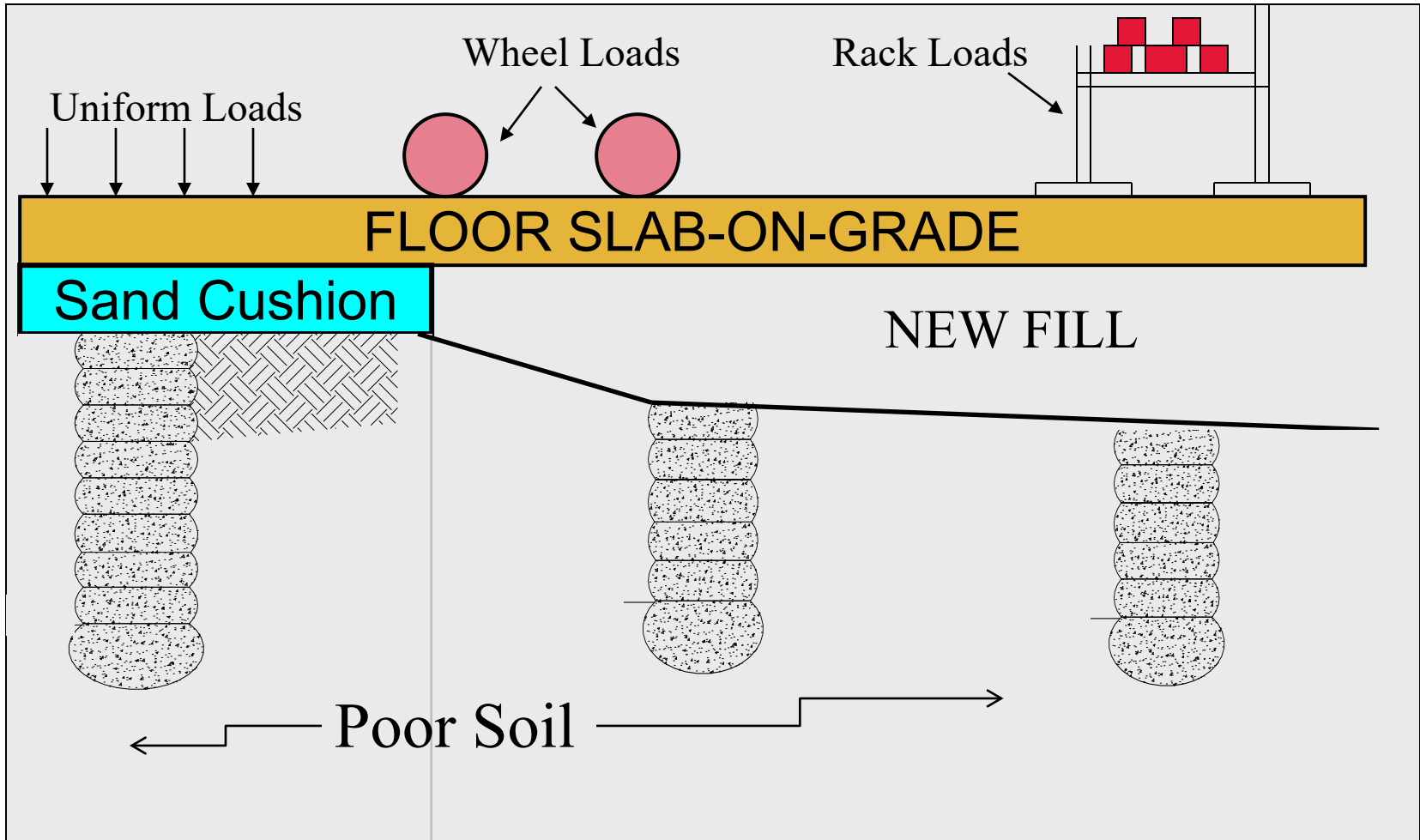
GI Engineer must account for overlapping stresses for adjacent footings

GI Engineer should include information on how far apart elements can be spaced beneath strip footings



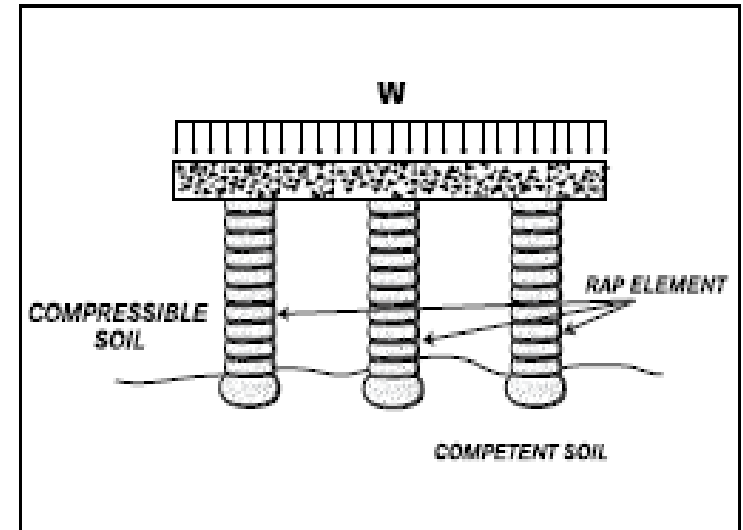


## Typical Layout for RAP below Footings



## Design Considerations

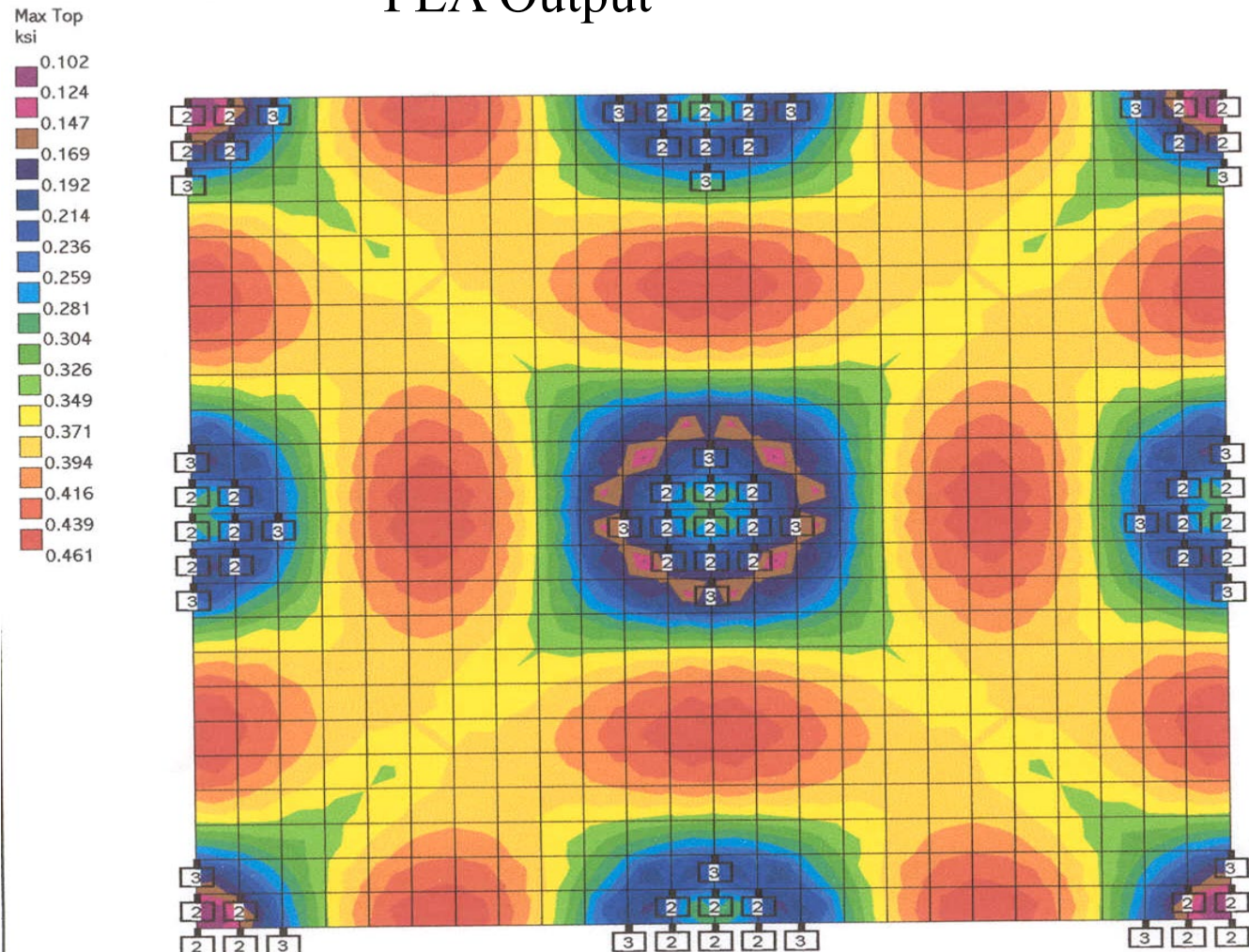
- Floor Loading
- Construction/Expansion Joint Spacing
- Pier Stiffness Modulus
- Pier Spacing
- Slab Thickness
- Concrete Compressive Strength
- Fill Thickness





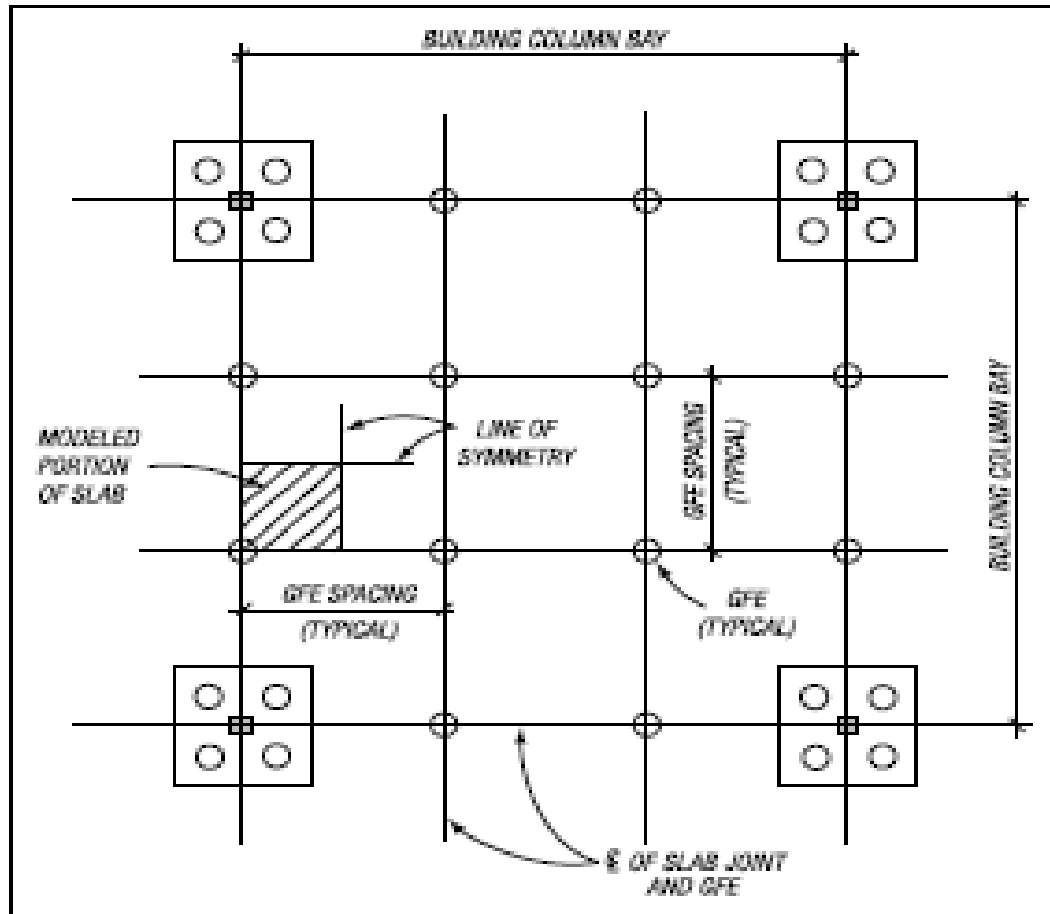
- The slab-on-grade over ground improvement will be supported over a variable subgrade.
- Assign spring constants at nodal points to the stiff ground improvement elements and to the less stiff surrounding soils.
- Design pier spacing so that the shear and bending stresses produced are less than modulus of rupture with adequate safety factor.

## FEA Output



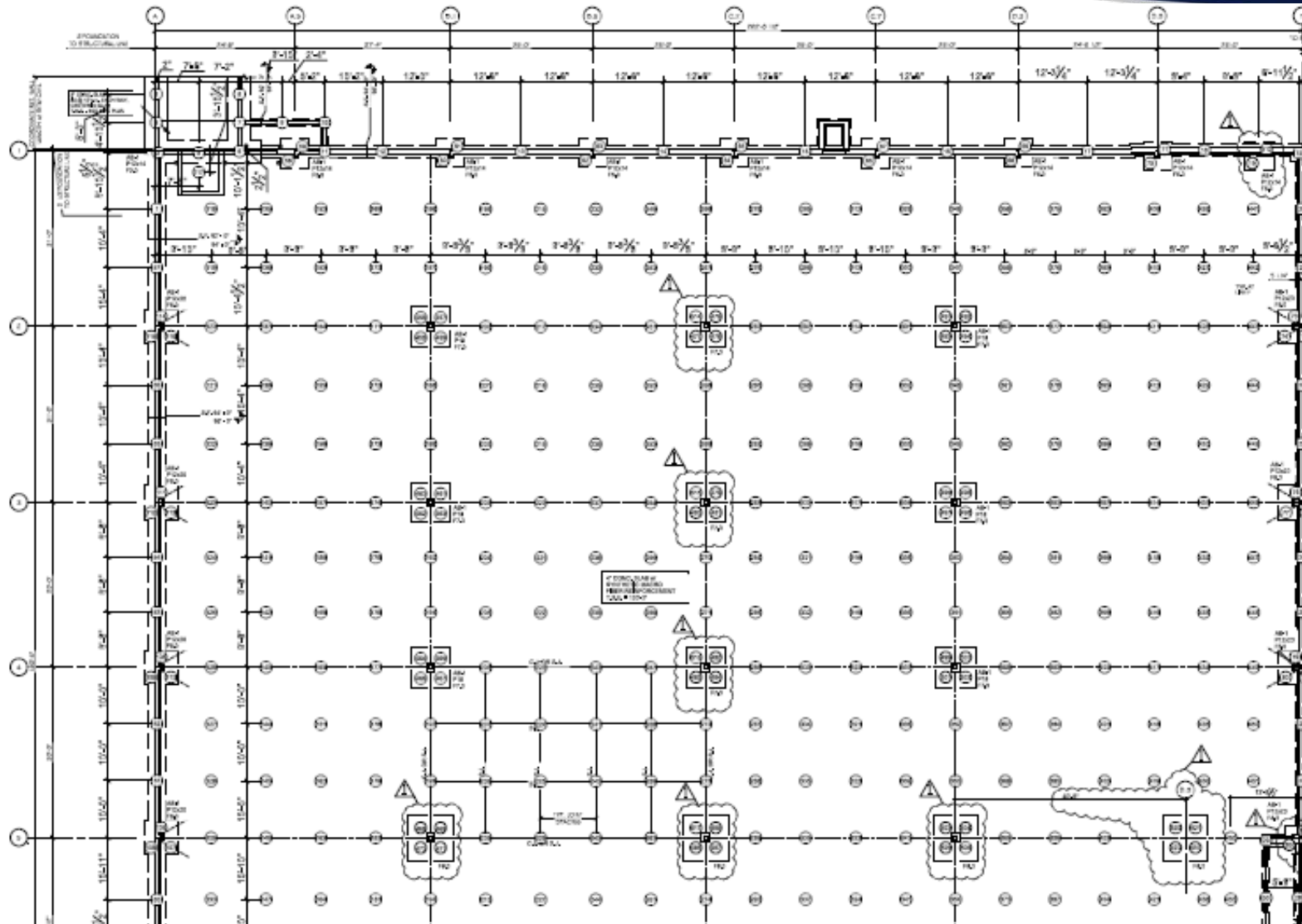


The spacing of RAP elements below a floor slab will often be controlled by CJ spacing.

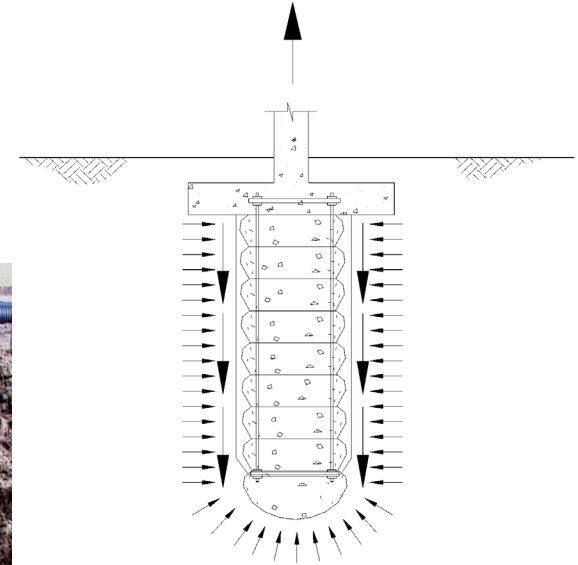
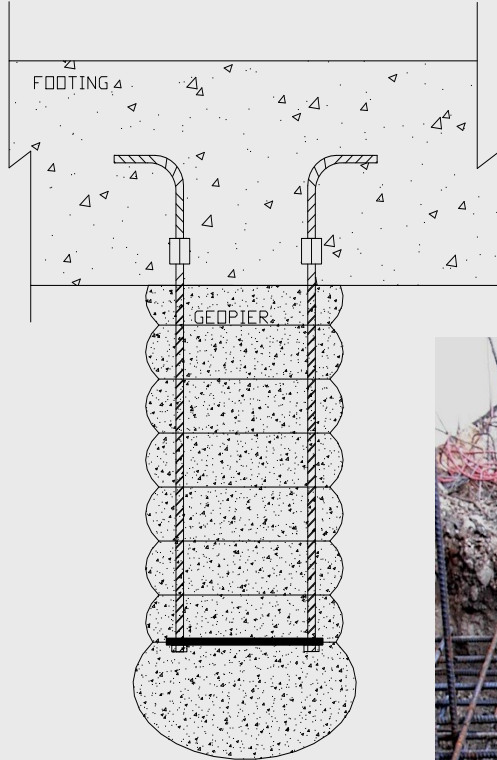


# GI Design

**GROUND  
IMPROVEMENT  
ENGINEERING**



## Typical Floor Slab Pier Layout



Uplift Resistance



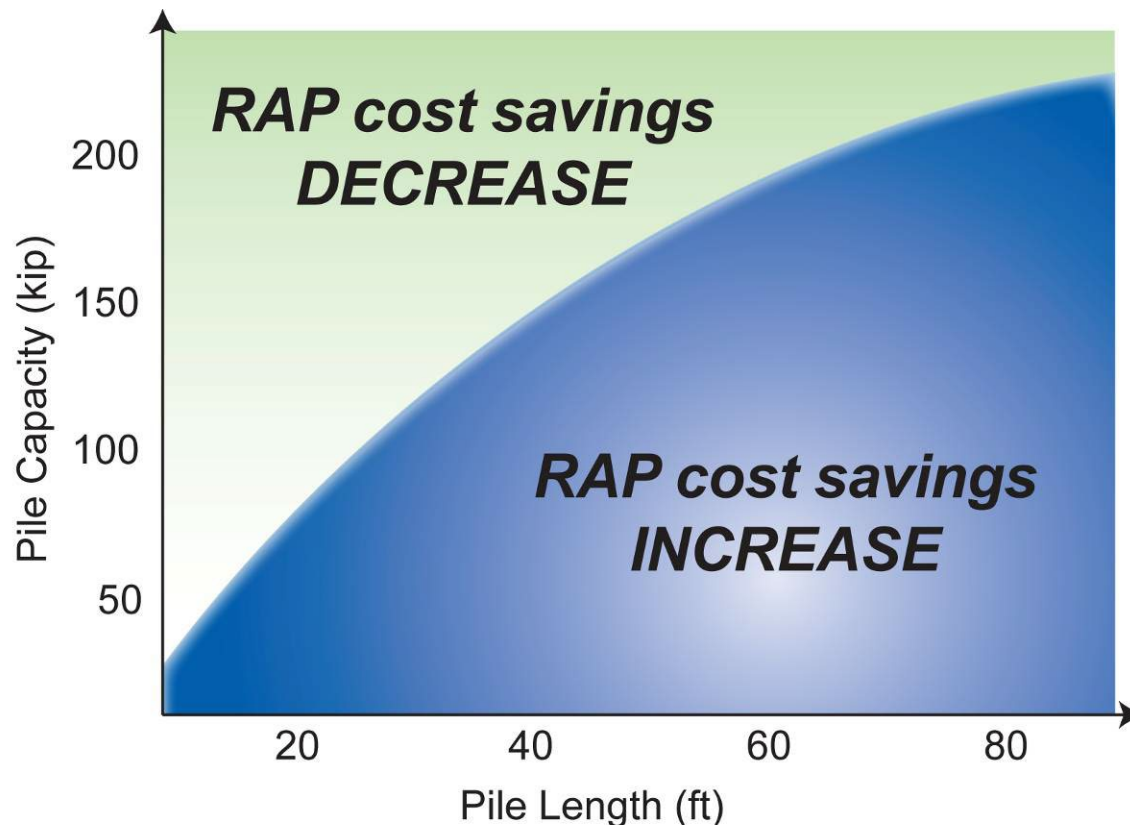
## Delegation of Responsibility

- EOR provides design criteria, develops specification, reviews GI design
- GI Designer provides design as a deferred submittal that shows compliance with EOR requirements (bearing pressure, settlement control)
- GI Designer develops quality control plan.



## Economics:

- Often provide a 20% to 40% cost savings in comparison with deep foundations



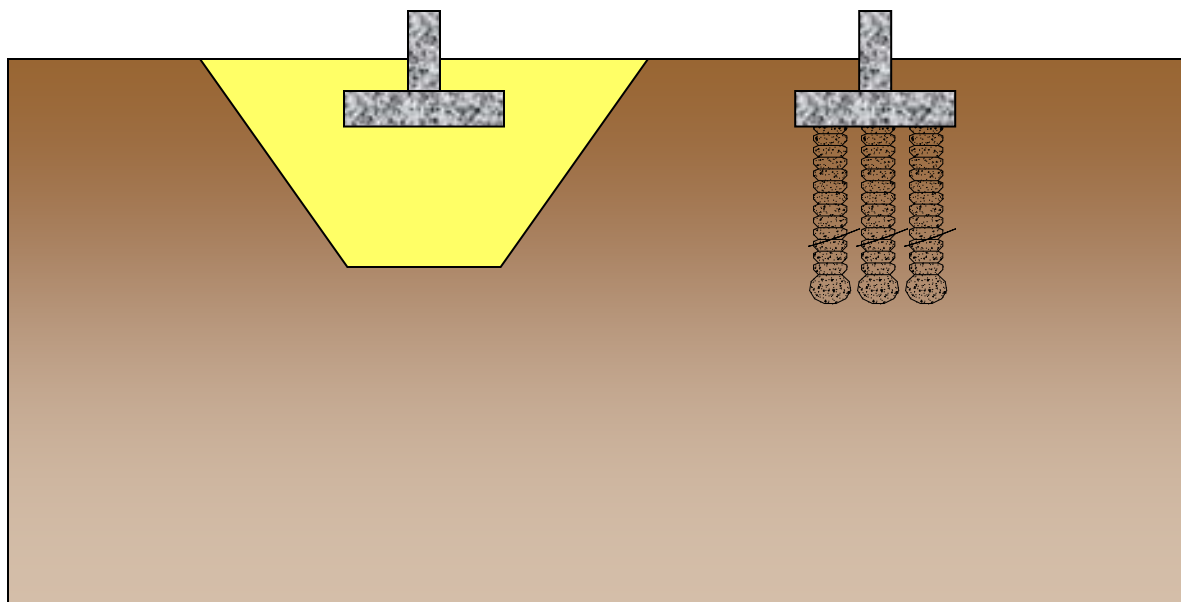
Additional benefits:

- Speed of construction



## ***When to consider:***

- **Poor soils sites (soft to stiff clay and silt, loose to dense sand, organic silt and peat and variable, uncontrolled fill)**
- **Tank applications**
- **Heavy column loads**
- **Contaminated soil sites**
- **Overexcavation exceeds about 4 feet**
- **Alternative to drilled piers / ACIP piles**





## Foundation Support



**Flying Tee – Tulsa, OK**  
GP3 (Drill & Fill)



**The Muse – Oklahoma City, OK**  
Impact (Displacement)



## Foundation Support



## Amazon Distribution Centers

Tulsa, OK  
Bondurant, IA

Kansas City, KS  
Colorado Springs, CO

Boise, ID  
Amarillo, TX



## Foundation & Floor Slab Support



### **Okana Resort & Water Park – Oklahoma City, OK**

- 11-Story Hotel
- 4-Story Parking Garage
- 2-Story Family Event Center
- Indoor Water Park



## Foundation & Floor Slab Support



**Pratt Industries – Wichita, KS**



## Foundation Uplift / Lateral Resistance



**Alpha Chi Omega House**  
– Norman, OK



**KSU Indoor Football Practice Facility**  
– Manhattan, KS



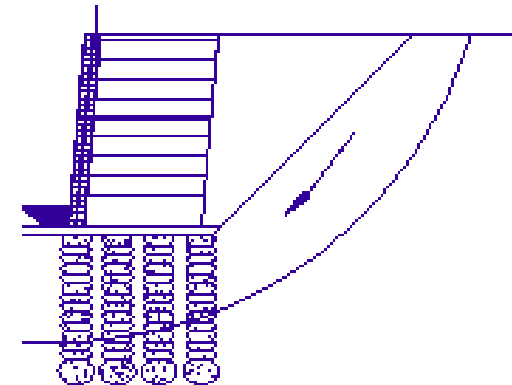
## Retaining Wall / Embankment Support



**WCC Grade Separation Walls  
- Wichita**



**KDOT US-69  
/I-435 Walls  
- Johnson  
County, KS**

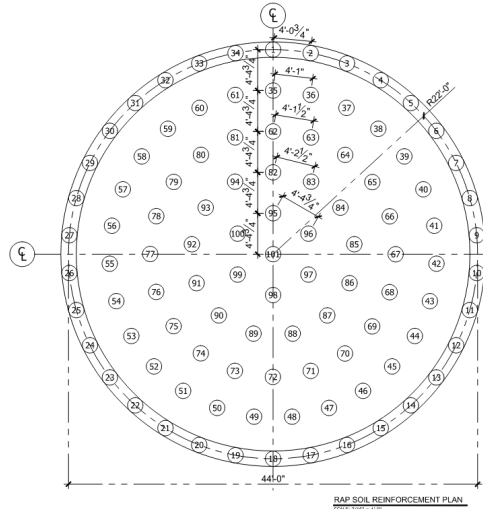




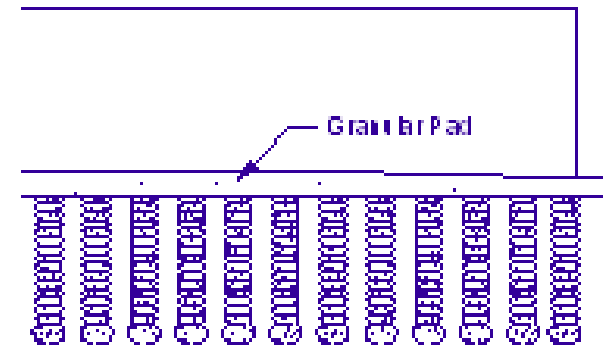
## Storage Tank Support



**Grain Bins – Multiple Locations**



**Velocity Midstream  
Naples Terminal Tank  
– Grady County, OK**





## Wind Turbine Support



Maverick Wind Project  
- Oklahoma



Traverse  
Wind  
Project –  
Oklahoma



Caddo Wind Project–  
Oklahoma



*The light at the end of the tunnel....*

**GROUND  
IMPROVEMENT  
ENGINEERING**



# Thank You!

**Vaughn Rupnow, P.E.**

[vrupnow@groundimprovementeng.com](mailto:vrupnow@groundimprovementeng.com)

(918) 313-4433

**GROUND  
IMPROVEMENT  
ENGINEERING**



Leading. By Design.



# GEOPIER<sup>®</sup>

**NSPE-OK**

OKLAHOMA SOCIETY  
OF PROFESSIONAL  
ENGINEERS